PICTURE OF THE MONTH

Illustrating the Merger of Tropical and Extratropical Systems

A. JAMES WAGNER

Extended Forecast Division, Weather Bureau, ESSA, Suitland, Md.

1. BACKGROUND AND LARGE-SCALE ASPECTS

On Sept. 10 and 11, 1968, a disturbance displaying many tropical characteristics moved northward just off the Atlantic coast into New England producing heavy rains with some flashflooding in portions of the Mid-Atlantic States and gusty winds along the Long Island and southern New England coasts. As in a similar case discussed by Fay [1], a weak circulation was detectable off the South Atlantic coast from the cloud patterns photographed by satellite, and the storm deepened as it moved northward near the coast, with the most rapid intensification occurring well north of what would ordinarily be considered tropical waters.

The composite photographs made from the APT transmissions from the ESSA-6 satellite clearly show an organized cloud system with indications of weak circulation located off the South Atlantic coast on September 9 (fig. 1), at a time when available surface reports did not give a definite indication of a closed center. Note the large cloud system centered over the Great Lakes area. This was related to a slowly moving extratropical storm system centered at the time over Wisconsin. The large band of clouds extending northeastward was associated with an active quasi-stationary front, and the cloud mass extending southward to northern Arkansas was probably related to instability due to cold air and cyclonic curvature aloft. Patches of convective activity were located near the Gulf Coast in the tropical air ahead of the cold front. The weakly banded structures in the Ohio Valley were related to areas of mild prefrontal instability.

The extratropical system moved slowly eastward with very little change of shape by the next day (September 10) except that the prefrontal cloudiness, now over Pennsylvania, was more solid and did not show banded structure. The tropical system appeared perhaps less well organized than the previous day, with some indications of a circulation center as far east as 35°N. and 70°W. No surface reports were found to support a storm center in that area, and available reports did require placing a center not far from the Carolina coast due to a southeast wind at Hatteras. Note the relatively dark (clear) area over southern New Jersey and the Delmarva Peninsula.

By midmorning of September 11, the tropical system was over central New England with a cloud structure suggestive of a warm front extending southeastward. Several bands of a convective nature pointing toward the storm center were located over the water south of the storm, but did not actually extend into or near the center. The cloudiness associated with the cold air and weak closed Low aloft was centered over Ohio, but the two cloud systems had to all appearances merged on September 11.

The paths of the tropical and extratropical Lows as obtained from the 3-hr. surface analyses prepared by the Analysis and Forecast Division of the Weather Bureau at the National Meteorological Center are shown in figure 2 for September 10 and 11. Center positions at 1200 GMT are marked with large numerals giving the date to facilitate comparison with the satellite photos in figure 1.

The position circle for the tropical system on the 9th does not imply that a closed center was definitely established at that time, but is in the area of apparent maximum surface cyclonic vorticity. The path of the tropical storm discussed by Fay [1] is also shown for comparison purposes.

It is of interest to note that the computerized circulation analog selector used in the Extended Forecast Division as an aid in the preparation of the 5-day forecasts picked the 5-day mean circulation immediately preceding hurricane Hazel as the best (from 20 yr. of record) on the basis of percentage of grid points with like sign of height anomaly over an area extending from the central Pacific to the western Atlantic.

Figure 3 shows the observed 5-day mean circulation and its departure from normal for the 5-day period Sept. 7–11, 1968, at the end of which the tropical disturbance moved up the Atlantic coast. Of interest are the deep trough in the Gulf of Alaska, the strong ridge over the Rockies, the trough in the Midwest, and the ridge off the Atlantic coast. This type of amplified wave pattern, which was not typical of the month as a whole (see fig. 1 and 2 of Posey's [2] article elsewhere in this issue), is necessary to bring any type of disturbance up the Atlantic coast with a greater than normal northward component of motion. The daily 700-mb. charts preceding Hazel's devastation of the East Coast in 1954 as given by Krueger [3] show remarkable similarities with the 1968 situation over the eastern Pacific and North America, but the circulation was more strongly amplified in 1954.

The intensity of the tropical system in 1968 was at least an order of magnitude less than Hazel, but its intensity

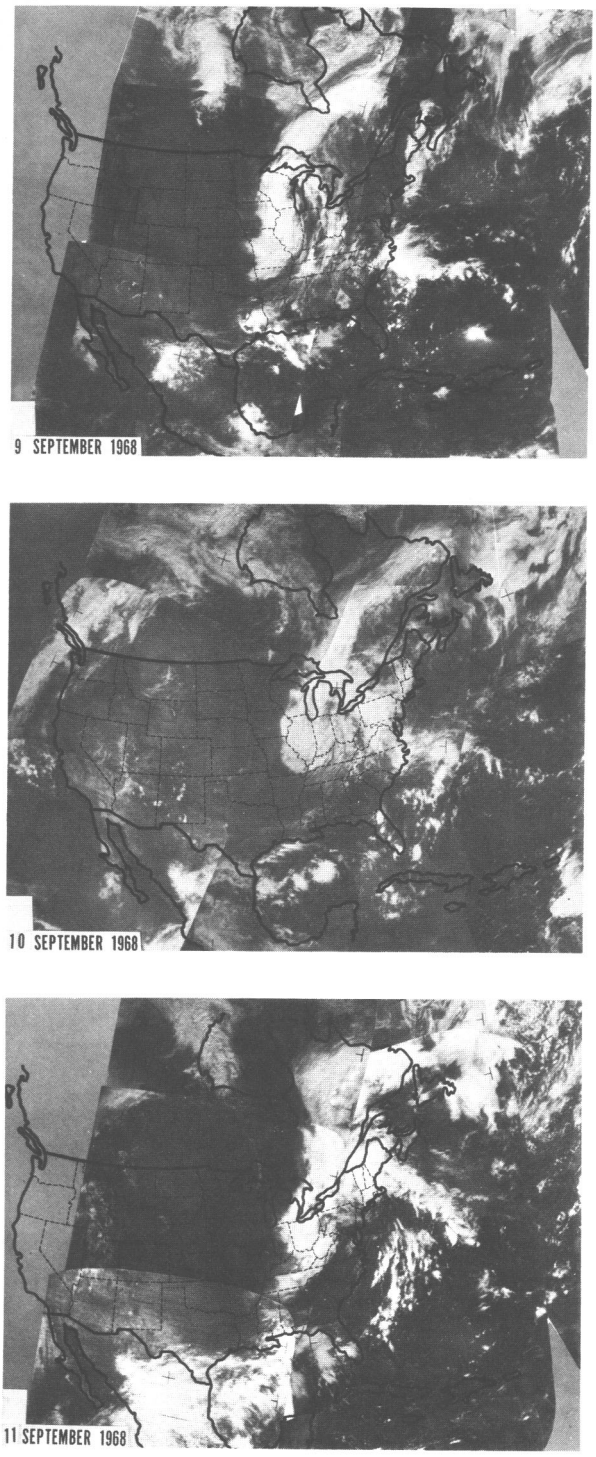

FIGURE 1.—Composite photographs from ESSA-6, APT, taken approximately 1500 GMT on the dates indicated. Note how the two cloud systems gradually merged into one by September 11.

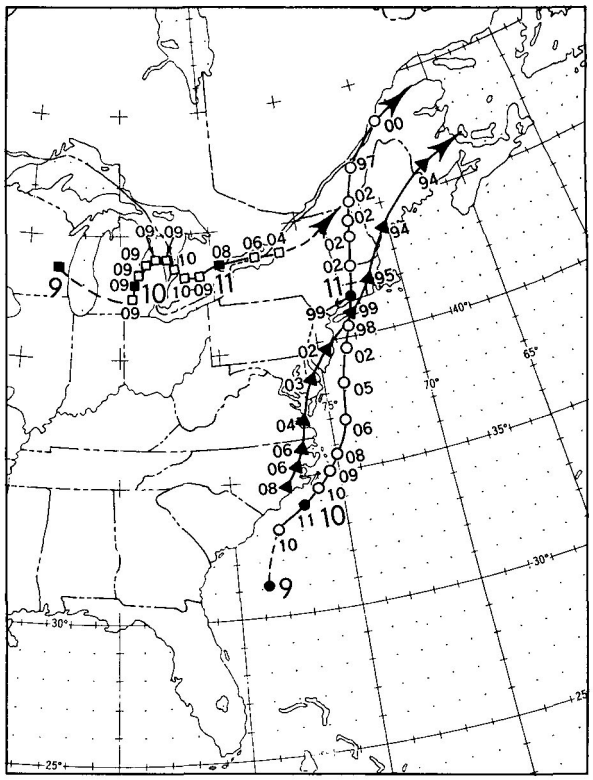

FIGURE 2.—Paths of the storms discussed in the text. Center positions are shown at 3-hr. intervals with tropical storm of Sept. 14–15, 1961, designated by triangles, storm of Sept. 10–11, 1968, designated by circles, and its associated extratropical Low designated by squares. Small numbers give central pressure in millibars with hundreds and thousands digits omitted, and large numbers opposite solid position symbols give dates of the 1968 storms next to the 1200 GMT positions. Dashed portions of paths are for continuity only and do not indicate exact locations. Data on the 1961 storm are taken from Fay [1].

and path were very similar to the storm of Sept. 14–15, 1961, discussed by Fay [1]. The path of the tropical disturbance of Sept. 10–11, 1968, was somewhat more northerly than that of the 1961 storm (fig. 2) but did not at any time show westward components of motion as did Hazel. This is in agreement with the fact that the amplification of the circulation in the recent situation was greater than in 1961 but less than with hurricane Hazel. (The 5-day mean 700-mb. height pattern associated with the 1961 storm was not selected at all by the analog program.) This illustrates the difficulty of phasing in analogs of large-scale circulation with analogs which are good in one detail of a situation but poor in the larger broadscale aspects.

2. SMALL-SCALE ASPECTS AND EVIDENCE OF TROPICAL NATURE OF STORM OF SEPTEMBER 10–11, 1968

On September 10, while the storm center was weak and moving slowly northward just east of Cape Hatteras, several areas of heavy precipitation developed in the Mid-Atlantic States. The precipitation distribution is particularly interesting in that except for Cape Hatteras itself, which received over 5 in. and was very near the storm center, precipitation amounts were relatively light along the coast everywhere south of the New York City area. The storm totals for the Maryland-Delaware area (fig. 4) graphically point this out. Over 6 in. of rain fell in northwest Baltimore leading to flashflooding and the death of two persons when their cars were swept off the road into a stream, while several stations in the Delmarva Peninsula reported a trace or none. (Note relatively cloud-free area there on photograph for September 10 in figure 1.)

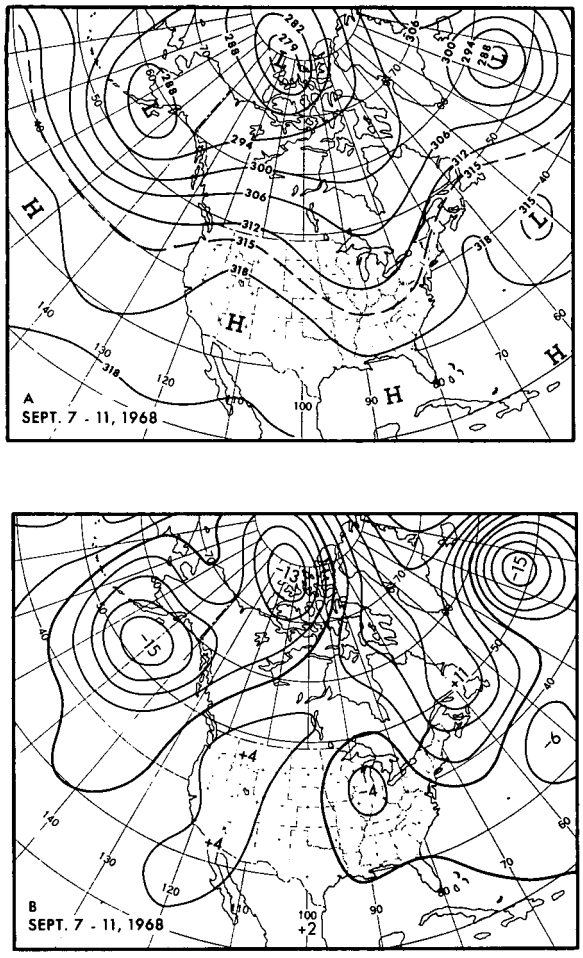

FIGURE 3.—(A) Mean 700-mb. height contours and (B) departure of 700-mb. mean from normal (both in decameters) for Sept. 7–11, 1968.

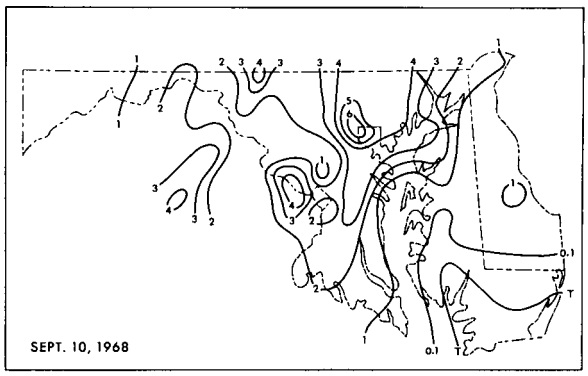

FIGURE 4.—(A) Rainfall distribution over Maryland, Delaware, and portions of northern Virginia on Sept. 10, 1968. Note extremely heavy amounts in the western suburbs of Washington and Baltimore and the lack of precipitation over southern portions of the Maryland Eastern Shore. Isohyets are labelled in inches, and the analysis is based on records from about 100 stations.

From preliminary considerations, it is believed that the heavy rain inland was caused partially by orographic lifting of the humid tropical air moving westward at low levels to the north of the storm center. A persistent surface High located just east of Maine contributed to the broad easterly flow.

An additional factor seemed to contribute to the areas of heaviest rains near Baltimore and Washington. Surface winds converged in this area for several hours during the time of heavy rain. The Washington radar showed some cloud tops extending to near 40,000 ft. during the afternoon of the 10th. It is possible that a prefrontal squall line generated by the cold front approaching from the west may have somehow "phased in" with the moisture-laden east winds coming around the tropical system to produce a region of persistent convergence and instability leading to the abnormally heavy rains. Just a few hours after the time of heaviest rain, the 0000 GMT 850-mb. winds at Washington and Norfolk also indicated convergence at that level east of Washington.

The record of a recording rain gage located in the southern extension of the rain area which had its core over Baltimore shows that 3 in. of rain fell between 2:30 and 6:30 p.m. EST with the bulk of it in a 3-hr. period (fig. 5). This is near the time of maximum diurnal convective activity.

It is thus apparent that until the storm approached Long Island, most of the precipitation over land was not associated with the activity near the center of the tropical disturbance, but with interaction of the moist outer flow around the tropical system with the circulation of the extratropical Low in the Great Lakes and with topographic features. The relative (and in some places absolute) dryness near the coast may have been due to some sort of compensating subsidence between the tropical center and the convergence line farther inland.

It is interesting to note, before leaving the discussion of precipitation, that on the afternoon of September 8, before there was any circulation at the surface and only a weak short wave trough aloft in the vicinity, Tallahassee, Fla., reported over 6 in. of rain, with about 5 in. falling within 1 hr.

The rapid deepening and intensification of the storm as it approached Long Island were reminiscent of the 1961 case discussed by Fay [1]. Although there was probably suitable divergence aloft in the current case as in the 1961 storm, it is also of interest to note that the average water temperature in the area off the Delaware coast for the first 10 days of September 1968 was 80°F., which is 4°F. above normal for that time of year. The warm water may also have contributed to the deepening and the rainfall by supplying additional sensible and latent energy to the system. It is also perhaps significant that a water temperature of 80°F. is just below the threshold level suggested by Palmén [4] as being a necessary condition for tropical storm formation.

Although the surface synoptic maps prepared operationally every 3 hr. by the Analysis and Forecast Division of the Weather Bureau at the National Meteorological Center did not indicate anything lower than an extrapolated center of 1002 mb. until after the storm had come inland over Connecticut, a later inspection of the hourly teletypewriter reports revealed pressures of 998.6 mb. and falling rapidly at Islip, N.Y., at 1000 GMT with a southeast

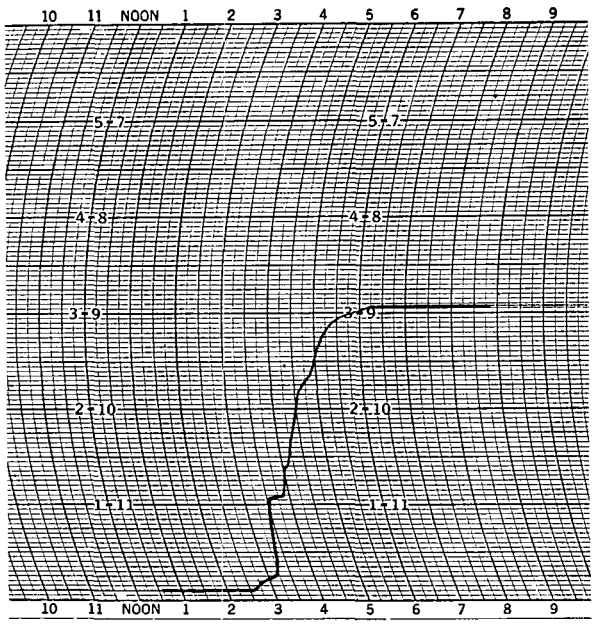

FIGURE 5.—Rainfall record for Sept. 10, 1968, from recording rain gage at the Maryland Tobacco Experiment Farm, Upper Marlboro, Md. (located about 15 mi. east of Washington, D.C.). Pertinent portion of trace was emphasized by hand for clarity of reproduction.

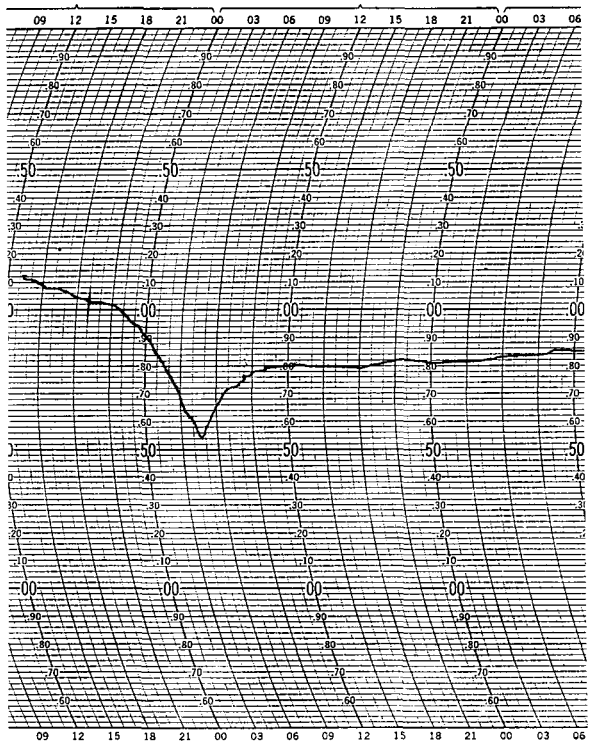

FIGURE 6.—Barogram for Sept. 11, 1968, from Islip, N.Y. (located near the south shore of Long Island about 40 mi. east of New York City). The barograph appeared to be set about 0.05 in. higher than the official hourly station pressure readings reduced to sea level.

wind of 18 kt., and 1000.6 mb. and rising rapidly with a southwest wind of the same speed just 1 hr. later. These reports indicate that the storm center must have passed a short distance west of Islip with a central pressure of 998 mb. or a little less at the time of first landfall (fig. 2). The barogram from Islip (fig. 6) shows the type of trace characteristic of tropical storms. (Compare with fig. 10 of Fay's [1] article.)

Reports of distant lightning to the southeast from Atlantic City and Lakehurst, N.J., between 0500 and 0600 GMT and an outbreak of thunderstorms at most stations in the New York City area between 0700 and 0800 GMT suggest that convective activity occurred near and west of the center at about the time of maximum deepening, and moved north-northeastward with the center. Whether this convection was organized in such a way as actually to contribute to the deepening as it does in the formation of tropical storms at low latitudes is unknown. Apparently the convective activity off the New Jersey coast did not represent an advective movement of the line of heavy showers observed the previous afternoon in the Baltimore-Washington area. Rainfall amounts over most of Delaware and southern New Jersey were negligible, and no reports were received of convective activity over the land in those areas.

Several coastal stations from Boston to New York's Kennedy Airport reported gusts in the range of 30 to 40 kt., and moderately heavy rains mostly in the range of 1 to 2 in. occurred from Long Island up through the Connecticut River Valley to southern Quebec in advance of the center. The two coastal stations nearest to which the center passed, Islip, Long Island, and Bridgeport, Conn., both reported dewpoints of 70°F. for an hour or 2 near the time of lowest pressure. Since the storm was beginning to assume extratropical characteristics and merge with the system from the west near the time of landfall (fig. 1) it is unclear whether it "made the grade" as a true tropical storm according to the official definition. It is however possible that sustained winds of tropical storm strength may have occurred over the open water south of Long Island near and to the east of the center.

ACKNOWLEDGMENTS

The author appreciates the help of Mr. W. J. Moyer, ESSA State Climatologist for Maryland, in obtaining the rainfall reports used to prepare figure 4, and for the recording rain gage record shown in figure 5. Also thanks are due to Mr. C. W. Crockett, ESSA State Climatologist for Virginia, for furnishing additional reports for figure 4.

REFERENCES

1. R. Fay, "Northbound Tropical Cyclone—A Case History," *Monthly Weather Review*, Vol. 90, No. 8, Aug. 1962, pp. 351–361.
2. J. W. Posey, "The Weather and Circulation of September 1968—Cool Over Much of the Nation With Progression of the Long Waves," *Monthly Weather Review*, Vol. 96, No. 12, Dec. 1968, pp. 893–898.
3. A. F. Krueger, "The Weather and Circulation of October 1954—Including a Discussion of Hurricane Hazel in Relation to the Large-Scale Circulation," *Monthly Weather Review*, Vol. 82, No. 10, Oct. 1954, pp. 296–300.
4. E. H. Palmén, "On the Formation and Structure of Tropical Hurricanes," *Geophysica*, Vol. 3, Helsinki, 1948, pp. 26–38.